Tropical thin cirrus and relative humidity viewed from AIRS

by

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Motivation

- **Cirrus is an important component of Earth's climate**
  - Climatic mean & variability (e.g., Ramanathan and Collins, 1991, Nature)
  - Hydrological cycle (e.g., Baker, 1997, Science)
  - Direct/indirect forcing & feedbacks (e.g., Liou, 1986, MWR)
  - Stratospheric/tropospheric transport & chemistry (e.g., Holton et al., 1995, Rev. Geophys.)

- **Recent studies call into doubt understanding of Ci formation, maintenance, amount**
  - Gao et al. (2004), Science
  - Jensen et al. (2005), Atmos. Chem. Phys.
  - Peter et al. (2006), Science
  - Indirect effects poorly characterized (Haag and Kärcher, 2004, J. Geophys. Res.)
  - Retrieval algorithms not consistent (Thomas et al., 2004, J. Climate)

- **AIRS provides new and improved measurements**
  - Cirrus properties (e.g., D_e and τ_{VIS})
  - Upper tropospheric RH_i in presence of clouds (Gettelman et al., 2006, J. Climate)
  - Simultaneous observations of microphysics & RH_i
  - Powerful combination along with other A-train measurements

Outline

- **Explore AIRS observations of thin cirrus**
  - Tropical upper troposphere
  - Will not discuss:
    - Observations outside tropics, radiative impacts, thicker cirrus, thin TTL cirrus over deep convection, mixed-phase, multi-layer or water clouds
  - Will focus on:
    - Thin cirrus with $\tau_{VIS} \leq 1.0$
- **Fast clear-sky RT model coupled to thin Ci parameterization** (Yue et al., 2007, JAS)
- **Run retrieval globally over oceans**
  - 30 focus days
- **Compare cirrus retrievals to physical quantities such as RH_i, D_e and τ_{VIS} , etc.**
  - Are correlations expected/unexpected?
  - How do they compare with other results?

The fast retrieval approach – 1

- **Combine OPTRAN clear-sky radiances with a thin cirrus parameterization**

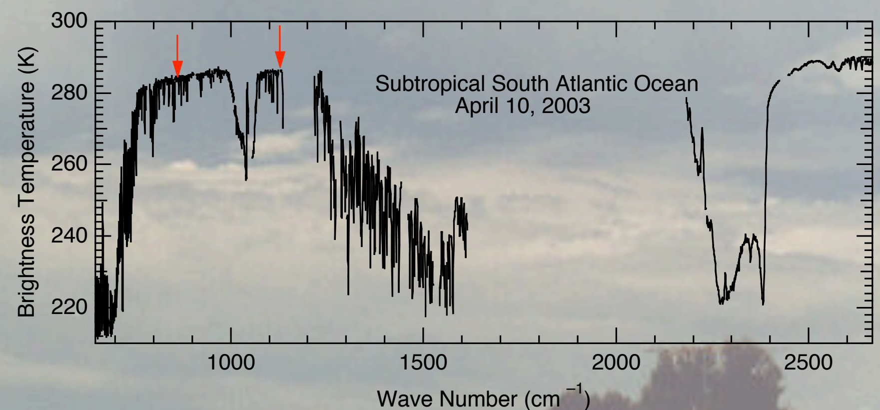
$$I_\nu = I_0(1-\varepsilon_\nu) + \varepsilon_\nu B_\nu(T_c)$$

$$\varepsilon_\nu \approx (1\text{-}\varpi_\nu)\tau_{IR}/\mu$$

$$\tau_{IR} \approx \frac{<Q_{ext,IR}>}{2}\tau$$

- **Cirrus represented by series of D_e and habit distributions**
  - Here we use Baum et al. [2005] models (using Yang et al. [2005])

- **Minimize χ^2 of observed and simulated AIRS radiances: best τ_{VIS} and D_e**
  - 14 window channels from 8.5–12 μm
  - Little sensitivity to channel choice



Yue et al., J. Atmos. Sci., in press

The fast retrieval approach – 1

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From AIRS L2 retrieval

Size and habit models impact here

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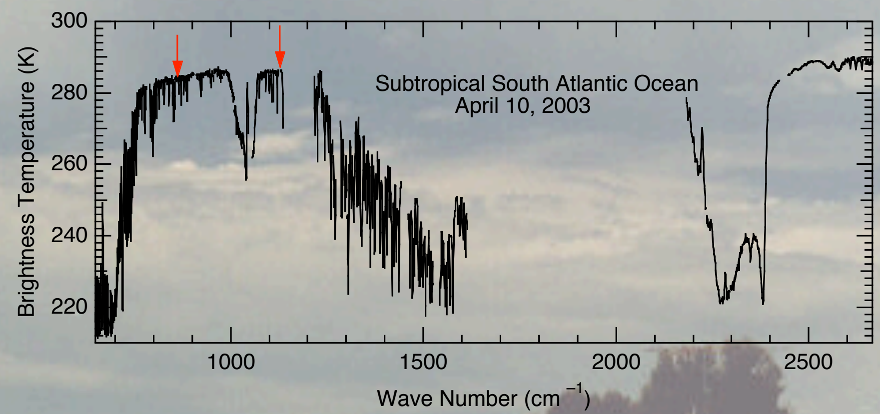

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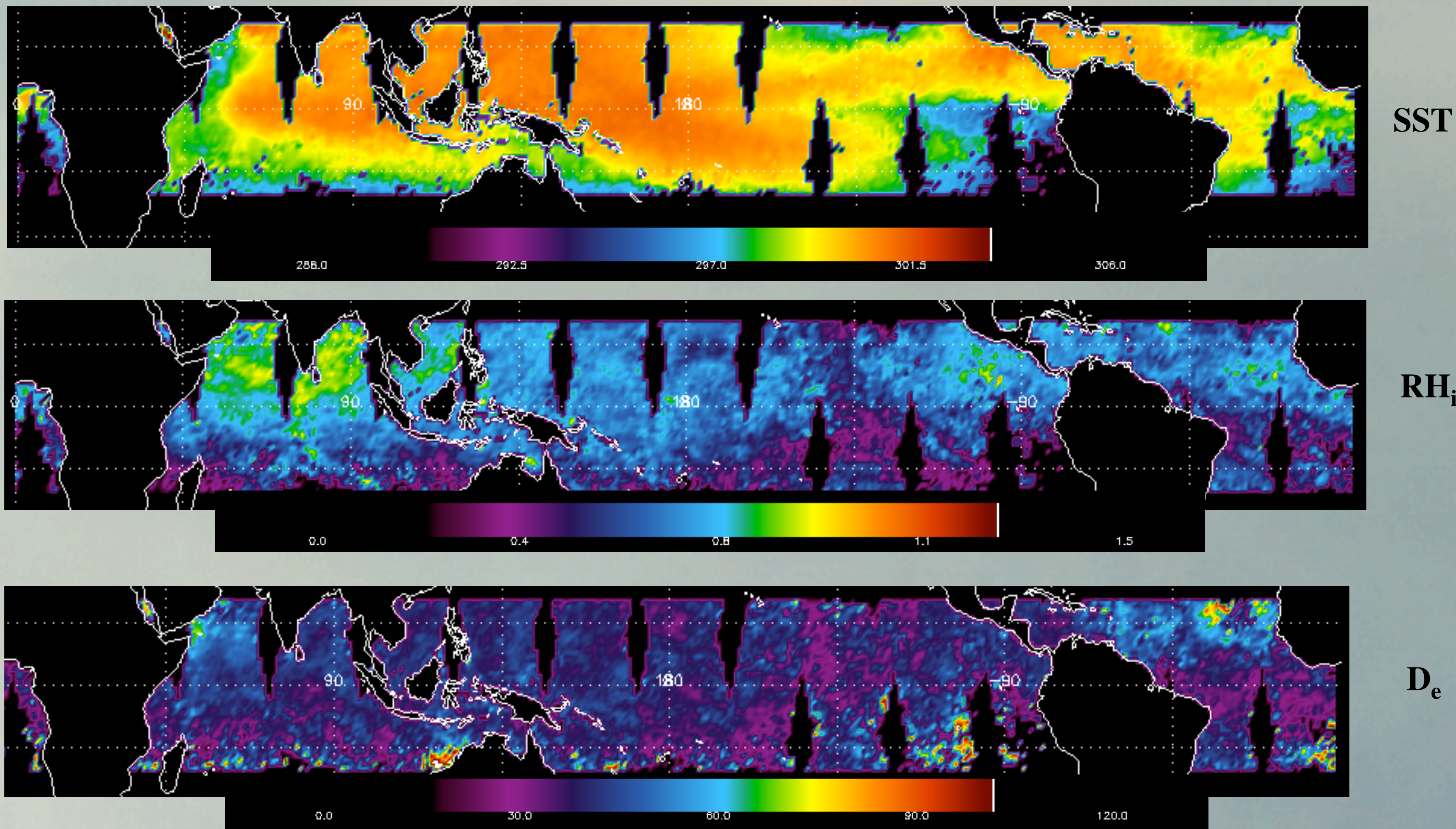
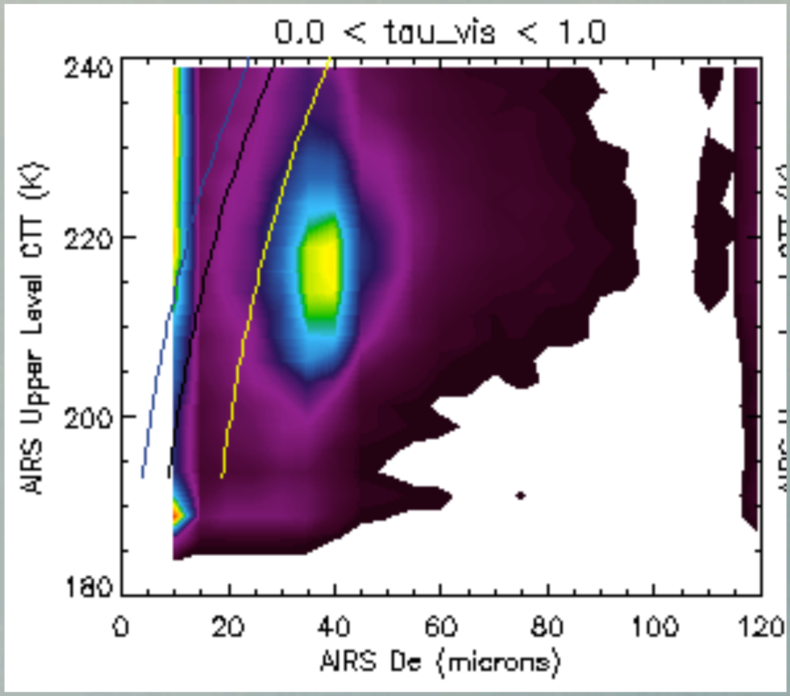
The fast retrieval approach – 2

- **Cirrus parameterization valid for ice clouds with:**
  - $\tau_{VIS} \leq 1.0$, only attempt if:
    - Single-layered cloud
    - Effective cloud fraction < 0.4
  - 10 µm ≤ D_e ≤ 120 µm (Baum et al. models)
  - Land fraction < 0.1
- **Use AIRS L2 Standard & Support (V5):**
  - Cloud top temperature (T_C) (Kahn et al., 2007a,b, J. Geophys. Res.)
  - T(z) and q(z) (AIRS validation issue; Gettelman et al., 2006a,b, J. Climate)
  - Emissivity and surface temperature (T_S)
    - Limited to ocean surfaces for now
- **Explore relationships between T_C, D_e, τ_{VIS}, RH, SST, etc.**
  - An example granule
  - Global oceans ±20° latitude for 30 days:

Retrieval sufficiently rapid for Global stats

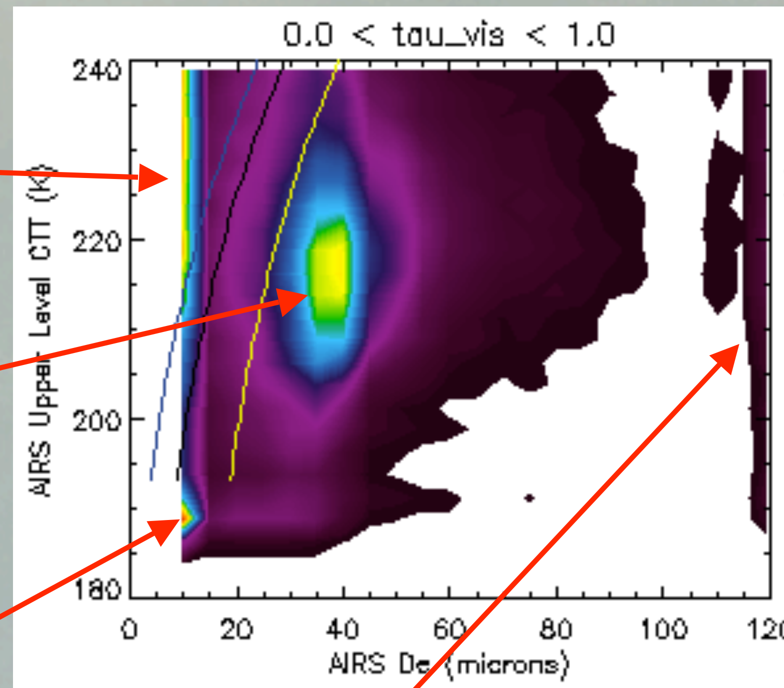


T_{CLD} vs D_e: Two primary size modes



- Joint PDF of AIRS T_{CLD} and D_e for thin Ci
- Black line → curve from *Garrett et al.* [2003]
- Two others are ± 1–σ variability

T_{CLD} vs D_e: Two primary size modes



Elongated mode associated w/ large errors in AIRS retrieval: discriminate bad/good cloud retrievals?

Large particle mode from 25–45 µm at warmer T

Small particle mode from 10–15 µ m between 190–200 K: need to resolve with smaller ice models!!

CALIPSO shows majority of AIRS spurious for this mode

Large particle mode (few cases): unidentified multi-layer or water clouds that AIRS calls high cloud?

T_{CLD} vs D_e: *In situ*, models, remote sensing differ

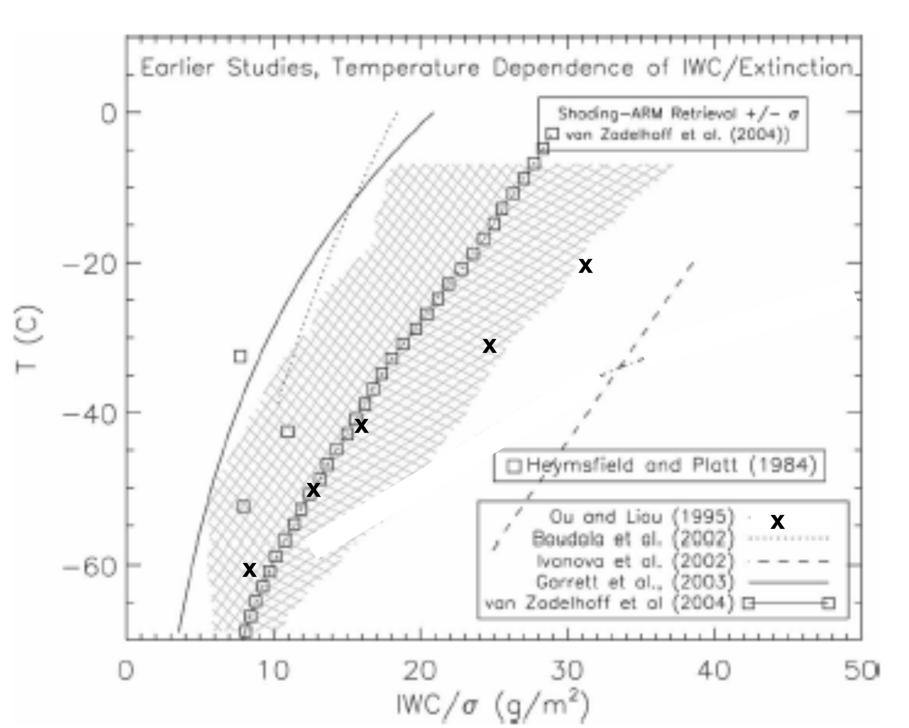
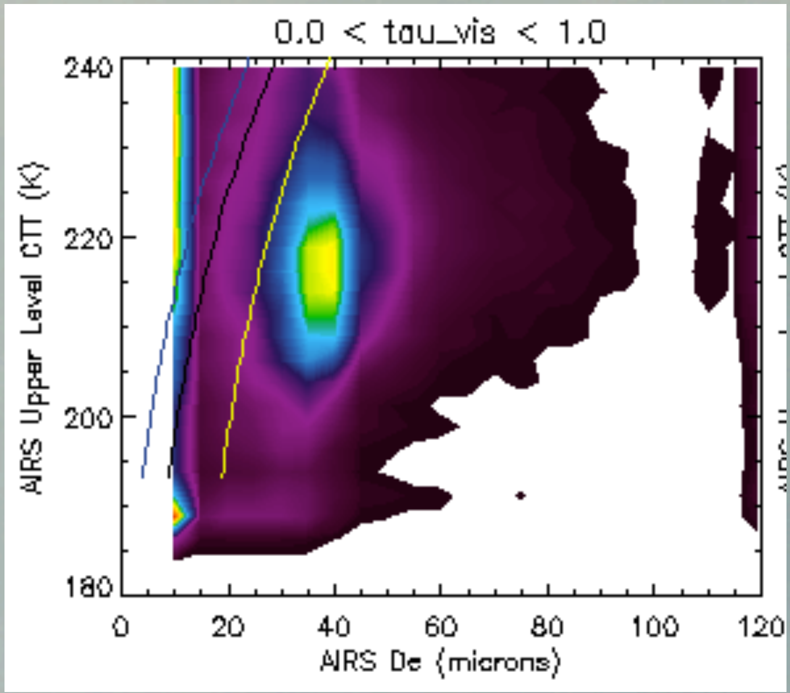


FIG. 1. Estimates of the ratio of ice water content to extinction from earlier studies.

From *Heymsfield et al*. [2006], JAOT



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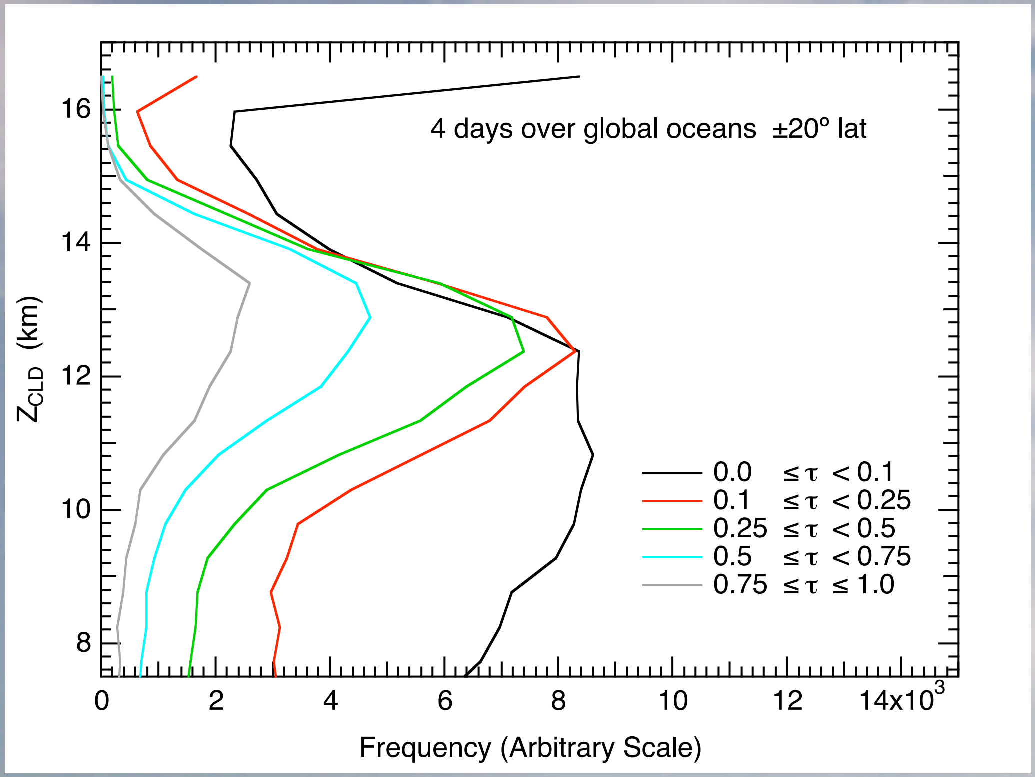
Relationships between cloud (and other) properties

- **Present series of 1-D histograms to describe features for 4 days**
- **Z_{CLD} vs. τ_{VIS}**
  - Where is thin cirrus distributed vertically?
  - How accurate is it? Differences with CALIPSO
  - Z_{CLD} from AIRS L2 retrieval: T(z) + T_{CLD}
- **SST vs. τ_{VIS}**
  - Remote Sensing Systems optimally interpolated SST (www.ssmi.com)
- **D_e vs. τ_{VIS}**
  - D_e and τ_{VIS} from fast RT model
- **RH_i vs. τ_{VIS}**
  - RH_i from AIRS L2 T(z) and q(z), following Gettelman et al., J. Climate (in press)
  - Only use q(z) > 15 ppmv: Gettelman et al. [2004] GRL

Z_{CLD} versus τ_{VIS}: Two height modes

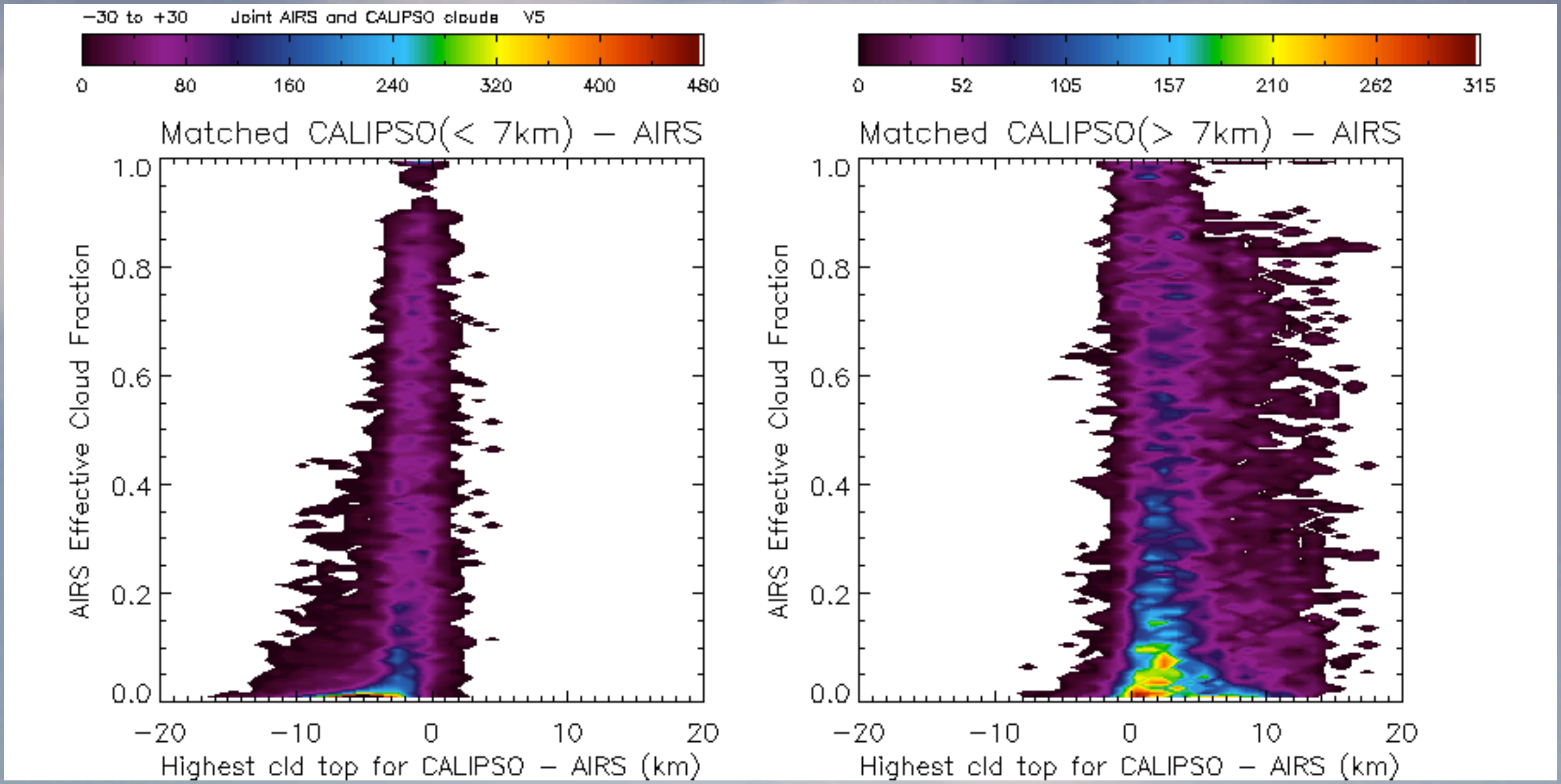


- **Histograms *not* normalized**

- **Two peak heights**
  - 12–14 km depending on τ_{VIS}
  - 16–17 km for low τ_{VIS} cases
    - Mix of real/spurious clouds

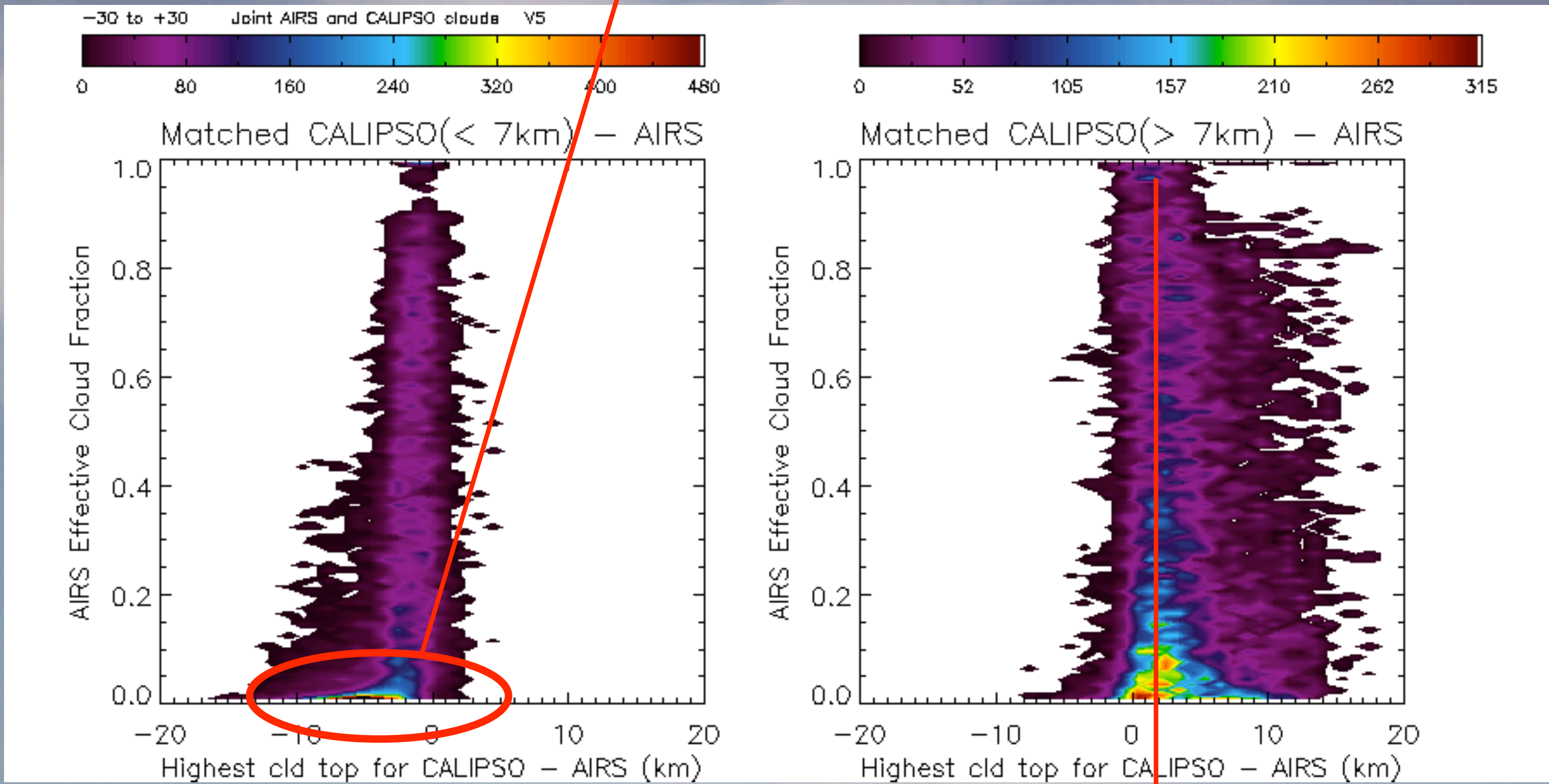
- **Largest # of cases for small τ_{VIS}**

CALIPSO–AIRS Z_{CLD}: Some bias + variability



CALIPSO–AIRS Z_{CLD}: Some bias + variability

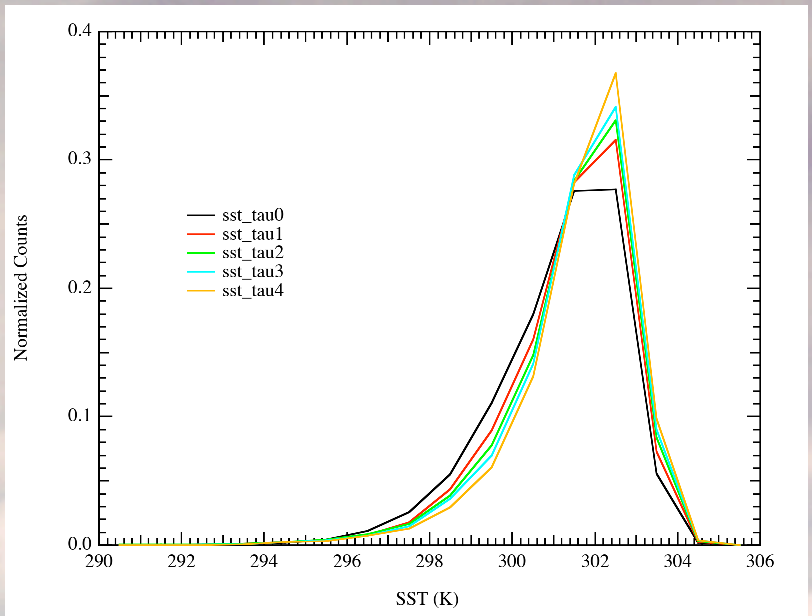
CALIPSO confirms many thin AIRS clouds spurious

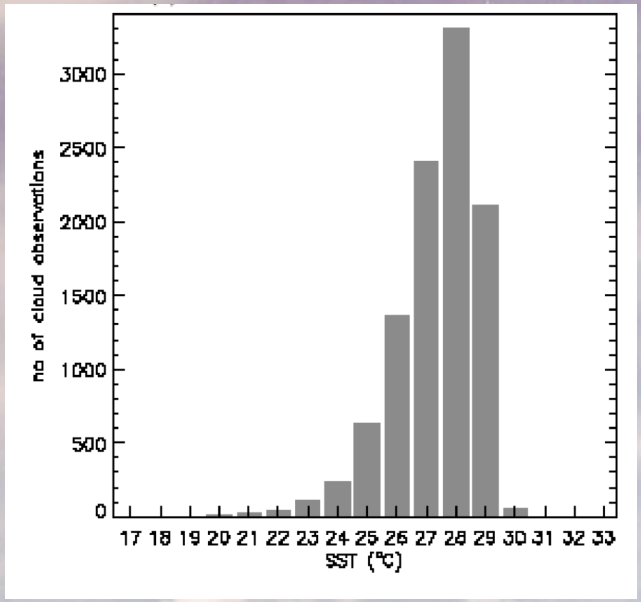


CALIPSO a few km higher

Variability largest for lowest ECF values

SST versus τ_{VIS}: Weak correlation

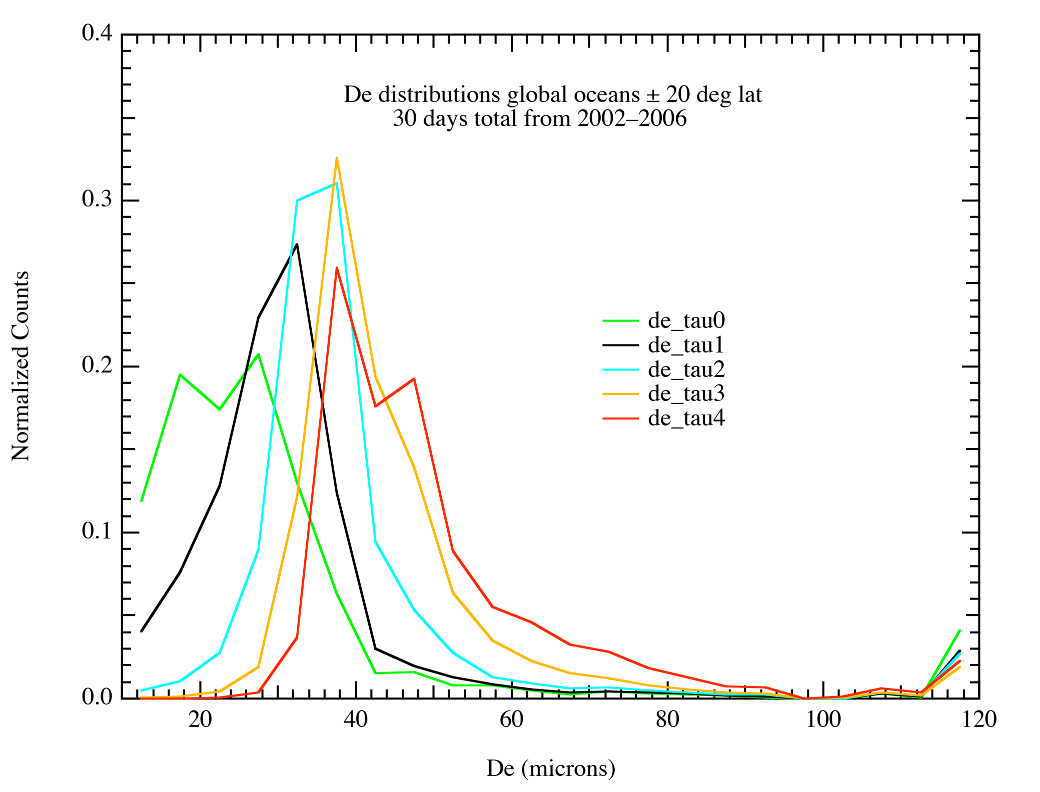




- **Remote Sensing Systems SST vs. AIRS τ_{VIS}**
- **Strongly increasing frequency of clouds with SST**
- **Peak consistent with other studies**

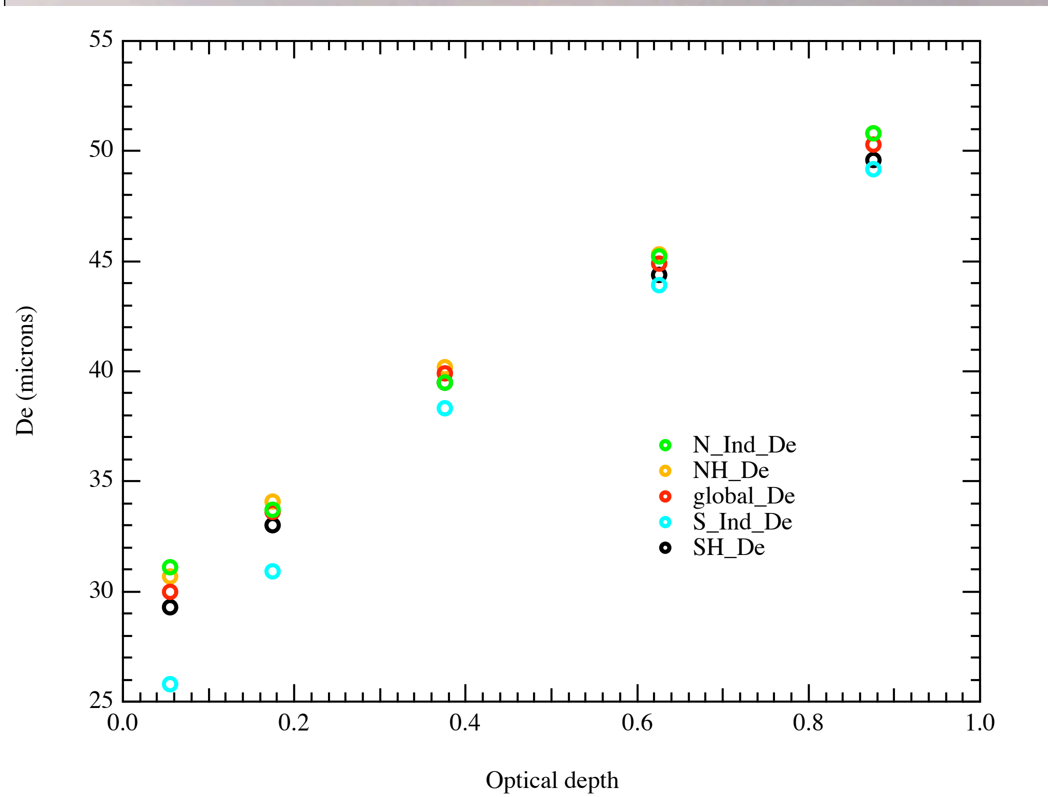
- **CLAES cirrus detection + SST (Clark 2005 JGR)**
- **Clearest regions → warmest SSTs**
- **Consistent with decrease in convective activity about 28–29 C: convection limits upper end of SST**

D_e increases with τ_{VIS} for thin Ci



- **Strong increase of D_e with τ_{VIS}**
- **Hemispheric/temporal differences small (not shown)**
  - Peak not constant with τ_{VIS}
  - Lowest τ_{VIS} bin may contain clear-sky cases

Somewhat larger D_e in NH vs. SH



- D_e for bins of τ_{VIS}
- 5 points for each τ_{VIS} are for 5different regions
  - NH, SH, global, N & S Indian Ocean
- Strong increase of D_e with τ_{VIS}
  - Indian Ocean results slightly more extreme than globally-averaged NH and SH results
- No detection/correction for aerosol (e.g., dust)

RH_i: Heterogeneous vs. homogeneous nucleation

Calculated RH_i outside (left) and inside (right) cirrus

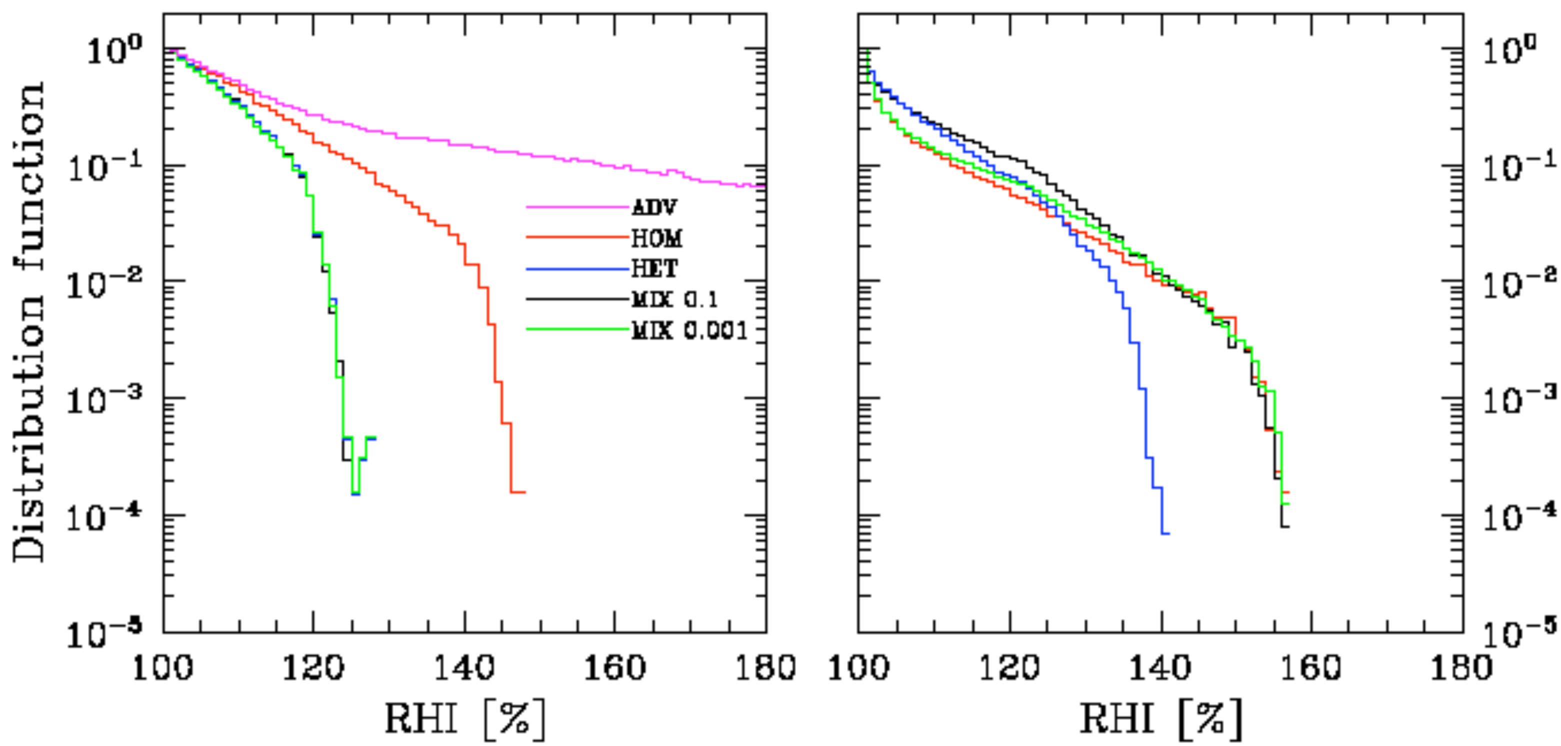
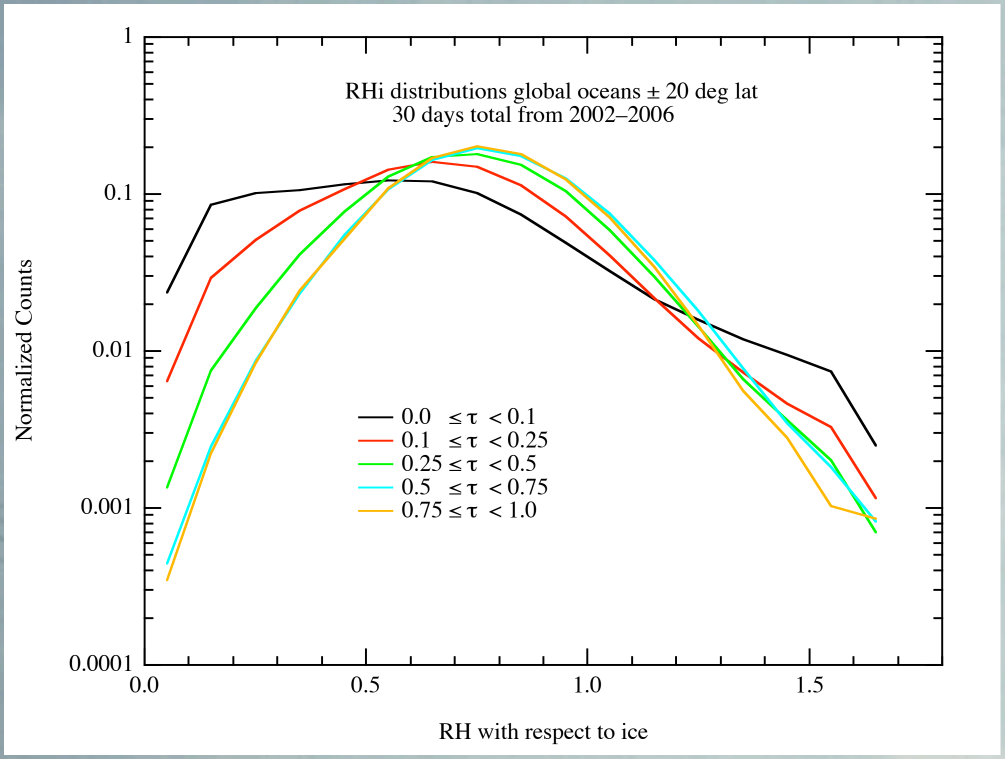


Fig. 1. Calculated distributions of RHI above ice saturation outside of (left panel) and inside (right panel) cirrus clouds. The distributions are normalized with the number of data points in the respective 100% bin and all RHI values were binned into 1% intervals. Liquid aerosol particles and heterogeneous ice nuclei freeze with different nominal ice nucleation thresholds (MIX n, n denoting the total concentrations of ice nuclei in cm^{-3}); the entire particle distribution freezes homogeneously (HOM), heterogeneously (HET), or not at all (ADV, left panel only). For details see text.

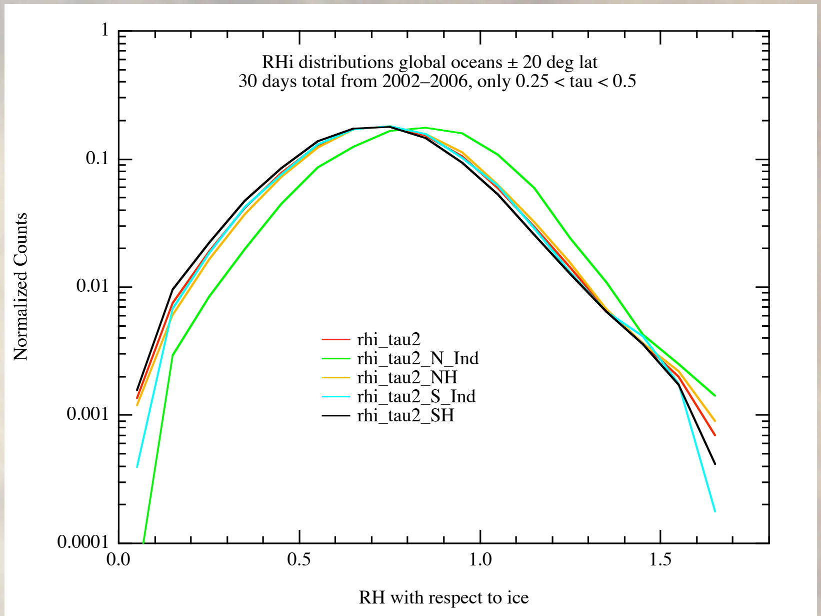
Haag and Karcher, 2003, ACP

RH$_i$ vs. τ_{VIS}: Higher τ_{VIS} and lower supersaturation

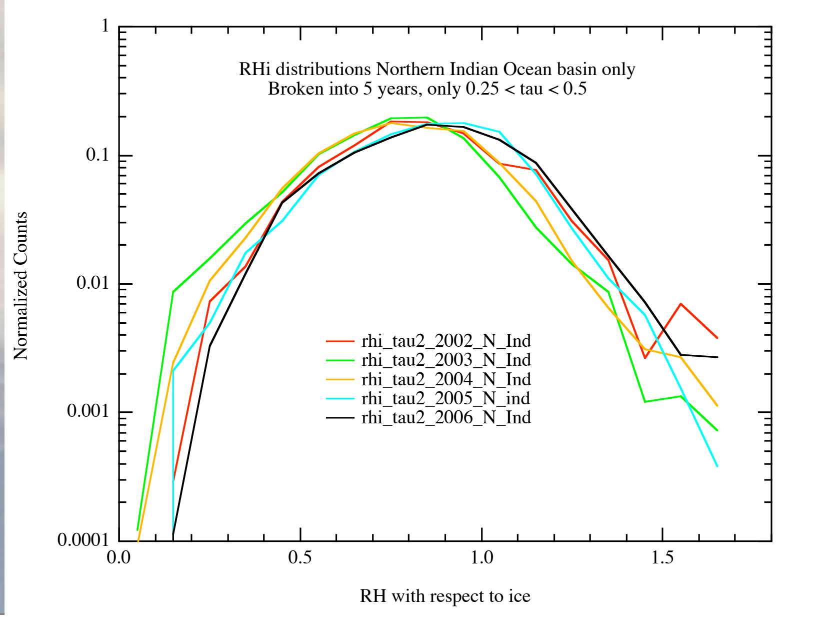


- **RH$_i$ vs. bins of τ_{VIS} (both derived from AIRS)**
- **RH$_i$ from *Gettelman et al.,* J. Clim (2006)**
- **Globally 1–3% supersaturation in tropical upper trop**
- **Within thin Ci 8–12% supersaturation**
  - **Ci have higher frequency than clear sky**
- **Distribution of supersaturation dependent on τ_{VIS}, hence D$_e$**

RH_i vs. τ_{VIS}: Temporal & Spatial Variability

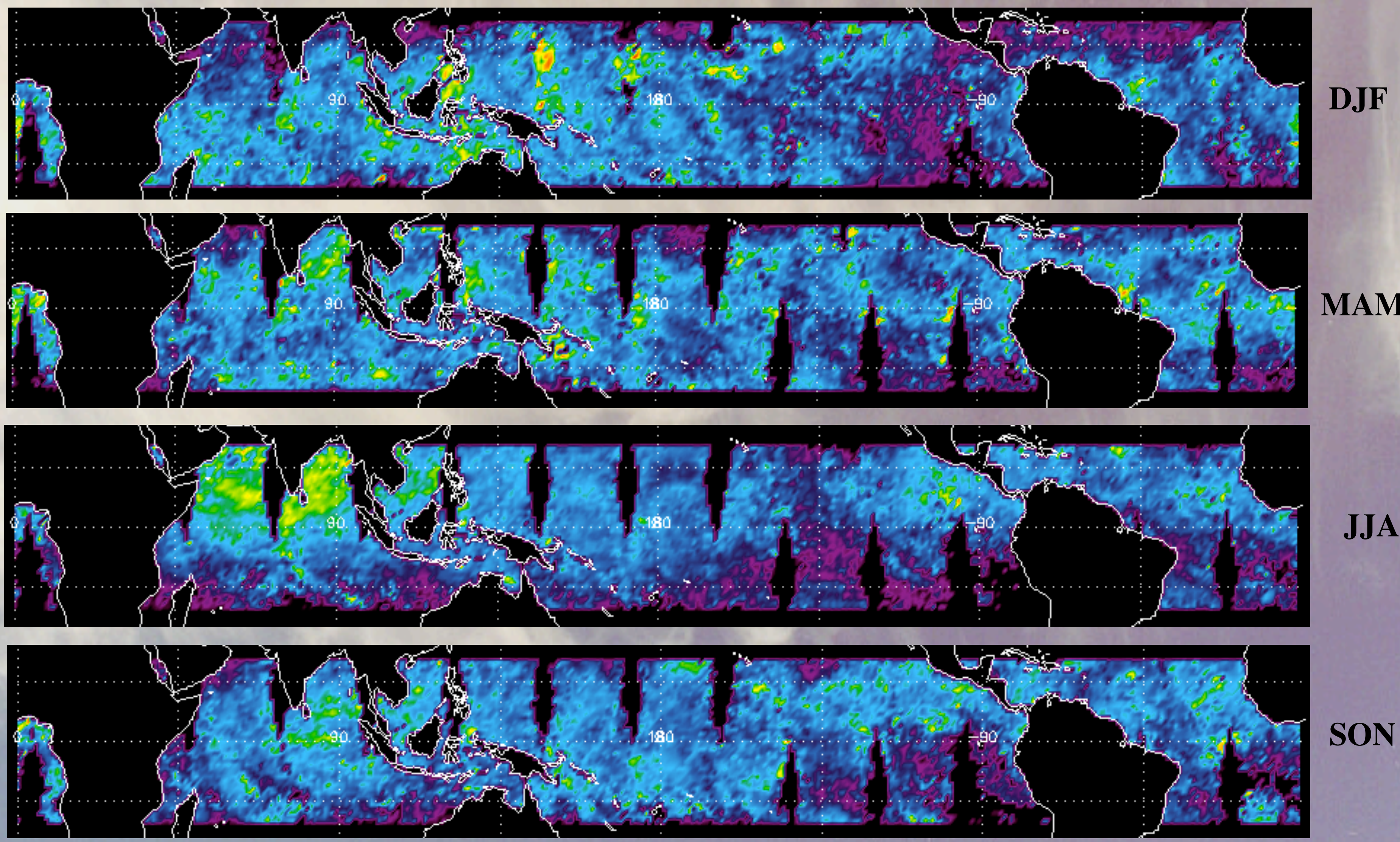


- **Upper panel: spatial variation**
  - **Global, NH, SH, N & S Indian Ocean**
- **For all values of τ, N Indian has 5–10% higher RH_i**
- **Speculation: Anthropogenic pollution inhibiting Ci formation and producing high RH_i (e.g., Jensen et al. 2005, ACP) ?**



- **Lower panel: temporal variation in N. Indian Ocean for 2002–2006**
- **Hundreds of thousands of retrievals**
- **Globally much less variability**
- **Other regions show less variability**

Seasonal Variation of RH_i within thin Ci



Summary and Conclusions

- **AIRS demonstrates utility in characterizing upper tropical troposphere**
  - Temperature, humidity, and tenuous clouds
- **Similarities/differences to in situ, surface-based, and GCM parameterizations**
  - Two primary D_e modes retrieved: 10–15 μm, 25–45 μm
    - Smaller mode dominated by spurious clouds
  - Dependence of modes on τ_{VIS}
- **1-D histograms reveal correlations to other quantities**
  - Z_{CLD} relatively invariant with τ_{VIS}
  - Thin cirrus frequency increases with SST, decreases above ~ 302 K
  - Very subtle differences of SST with τ_{VIS}
  - Strong relationship between τ_{VIS} and D_e
  - Connection between supersaturation frequency and τ_{VIS}/D_e

Future Work

- **Trajectory model? Relate Ci microphysical/optical properties to RH_i**
    - By cloud type, height
    - Clear air before/after cloud nucleation event

- **Apply to thicker clouds**
    - Scattering RT model
    - Use of CALIPSO for microphysical/optical properties

- **Further improvement of AIRS cloud fields**
    - Reconcile trends in frequency
    - Treatment of CO_2 (Hearty et al. 2006 AGU poster)
    - Spectral emissivity? Resolve residuals of obs-calc (e.g. Strow et al. talk in climate session today)
    - Single FOV retrievals: better cloud spatial information

All cloud photos taken from www.australiansevereweather.com